University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

Doctoral Documents from Doctor of Plant Health Program

Plant Health Program, Doctor of

4-2014

Optimizing Water Use through Management of Spatiotemporal Variation Using Site Specific Technologies

Laura J. Dotterer
University of Nebraska-Lincoln, bruner.33@gmail.com

OPTIMIZING WATER USE THROUGH MANAGEMENT OF SPATIOTEMPORAL VARIATION USING SITE SPECIFIC TECHNOLOGIES

by

Laura Jo Dotterer

A Doctoral Document

Presented to the Faculty of

The College of Agricultural Sciences and Natural Resources

In Partial Fulfillment of Requirements

For the Degree of Doctor of Plant Health

Major: Doctor of Plant Health

Under the Supervision of Professor Gary L. Hein

Lincoln, NE

May, 2014

OPTIMIZING WATER USE THROUGH MANAGEMENT OF SPATIOTEMPORAL VARIATION USING SITE SPECIFIC TECHNOLOGIES

Laura Jo Dotterer, D.P.H

University of Nebraska, 2014

Advisor: Gary L. Hein

Abstract:

The effects of landscape variability can be minimized through site-specific crop management. Variability in production agriculture affects profitability of operation mainly through yield impacts and the efficiency of input use. A field can be broken down into smaller areas called management zones. Management zones are created by an area in the field that has similar yield-limiting factors, and thus, the same rate of an input can be applied to that area to increase efficiency or yield.

Variable rate irrigation (VRI) is a site specific water management tool that can be utilized to apply the optimal amount of water on all acres resulting in increased overall yields. It has the potential to enhance water resources especially in areas with limited irrigation. The sector control system changes the pivot travel speed to alter the water application rates in each sector. Whereas, a zone control system varies rates in zones by pulse width modulation of electric solenoid valves. Defining field variability to build a prescription for water application typically uses soil electrical conductivity (EC) measurements. Tools are available to make irrigation scheduling decisions, which includes methods of feel and appearance of the soil, soil water content measurement, and soil water potential. Remote sensing imagery can also be important for in season and next year's evaluation of VRI prescriptions.

ACKNOWLEDGEMENTS

There are many people that I would like to thank in helping me in my journey of completing the Doctor of Plant Health (DPH) Program. I gratefully acknowledge the financial support from the USDA-NIFA National Needs Fellowship Program (Grant #2010-38420-20325). Thank you to the program director, Dr. Gary Hein, for his help and guidance from my start to finish within the DPH program. I would like to thank the program's committee members, Dr. Gerard Adams, Dr. Tom Hoegemeyer, and Dr. Robert Wright for their thoughtful advice. Thank you to Nancy Shoemaker for being helpful and encouraging. I am thankful for the many faculty members that have invest time in my learning process and challenging my critical thinking. I especially thank, Dr. Jill Pfister and Dr. Erich Grotewold from The Ohio State University for inspiring and encouraging me.

I am grateful for the support from the many people at DuPont Pioneer, especially those in the Western Business Unit office in Lincoln, NE. Thank you, Jeremy Groeteke and Dr. John Shanahan for all your time spent answering my questions, giving advice, and mentoring me.

Thank you to my colleagues at the University of Nebraska-Lincoln, in particular those in the DPH program for the discussions, fun, and friendships. I am grateful for the love and support from my family and friends all around the world. Thank you to my parents, Dan and Jo Bruner, for all the encouragement and believing in me. Most importantly, thank you to my husband, Jesse for your love, sacrifice, support, and for agreeing to this crazy adventure.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

SITE-SPECIFIC WATER MANAGMENT

Precision agriculture, precision farming, or site-specific management have all been used interchangeability and viewed as a method in production agriculture that utilizes a systems or holistic approach to farming. Traditional agriculture has viewed a field as one homogeneous unit with uniform application of inputs; whereas, site-specific management uses information and technology to account for field variability when making management decisions (Davis et al. 1998, Grisso et al. 2009). The gathering and use of information for crop production decision making and the automatic control of operations is one way to define site-specific management (Cox 2002).

The development of global positioning system (GPS) was significant to the beginning of site-specific management (Stafford 2000). In the 1970s, the U.S. Department of Defense placed satellites into orbit that provide radio signals for GPS to operate (Stafford 2000). Twenty-four satellites orbit the earth sending out radio signals 24 hours a day that are processed by ground receivers to determine the altitude, latitude, and longitude of the receiver's position within a few meters (Stafford 2000, Grisso et al. 2009). GPS technology is able to reference spatial variation in a field, enabling increases in efficiency when applying variable rate of inputs (McLoud et al. 2007).

The use of GPS was not available for site-specific management until the 1990s, but the beginnings of site-specific management started earlier in the twentieth century. The first yield maps were developed in 1928 by Eden and Makell (Stafford 2000); however, site-specific management concepts began to gain popularity when Johnson et al. (1983) proposed the idea of 'custom prescribed tillage'. They foresaw the age when site-specific management would change crop production through the use of information and technological advancements in automation, sensing and location systems. Matthews (1983) shared in the vision of site-specific management and expressed the need for crop management that varied the input quantities based localized areas.

The early implementation of site-specific technology was primarily driven by fertilizer industry specialists (Krishna 2013). Fertilizer specialists used site-specific technology to expand assessment of soil fertility and increase the efficiency of synthetic fertilizer (Krishna 2013). 'On-the-go' fertilizer mixing and application systems created by Soil Teq in 1985 were the first use of site-specific technology. The technology aided in creating a fertilizer application map based on information from grid soil samples and aerial imagery (Fairchild 1988). Unfortunately, satellites were not available for commercial use, making real time positioning of fertilizer machinery difficult during application (Stafford 2000).

Components of Site-Specific Management

The three main components of site-specific management are information, decision support, and technology (Grisso et al. 2009). Information is the core of site-specific management as information is collected using various technologies, stored, manipulated, and used for decision making and application (Stafford 2006). Factors that contribute to spatial and temporal variability, such as crop and soil characteristics, are important to incorporate into the database to use for interpretation and decision support by using geographic information systems (GIS) (Grisso et al. 2009). Information management is important as an enormous amount of data is collected in site-specific management, and the information needs to be manipulated through decision support processes (Davis et al. 1998).

Decision support uses computer programs and/or databases that integrate, analyze, and interpret data to develop management options. These tools provide information for farmers to make the best management decisions for each field on his or her farm (Grisso et al. 2009, Krishna 2013). One form of information outputted during the data analysis and decision-making process is treatment or prescription maps (McLoud et al. 2007, Grisso et al. 2009).

Information collection and use in decision support relies on the following technological tools (Davis et al. 1998): GPS, sensors, yield monitoring systems, GIS, and variable rate technology (Rains and Thomas 2000). GPS is important in site-specific management due to the need to return to the same locations within a field multiple times in a year. Satellites are continuously sending radio signals that are received and deciphered by GPS receivers. Four satellites are necessary for a receiver to determine its position on the earth's surface (Rains and Thomas 2000). The accuracy of position was decreased to within 300 feet by atmospheric conditions and U.S. Department of Defense offsetting the signal (selective availability errors). Another signal is needed to gain sufficient accuracy, and this signal comes from a known position from land or another satellite as a reference (Rains and Thomas 2000). Selective availability errors were turned off in 2000 by the U.S. Department of Defense, and future satellites lack this capability starting in 2007 (US Department of Defense 2007).

A differential global positioning system (DGPS) uses a GPS receiver as a base or reference station at a known location. The reference station uses its known position to compare to the location where the signal is received (McLoud et al. 2007). Recorded location data obtained at a roving receiver or a second GPS receiver is modified (corrected) from the reference station. The correction in the data occurs synchronously with data collection in the field through radio signals or during post data processing using software (McLoud et al. 2007).

There is more accuracy in using real-time kinematic (RTK) correction in determining location positions from GPS signals than DGPS. The relative accuracy of RTK is one centimeter, whereas DGPS is one to three meters (McLoud et al. 2007). RTK is a GPS system that uses a receiver as a reference station, and the second receiver as a rover (McLoud et al. 2007). The reference station can be temporary or permanent. The mobile unit(s) compares its measured carrier's phases with ones taken by the base station. The relative positions of the mobile unit(s) are calculated, but accuracy is limited to the exactness of the reference station location (McLoud et al. 2007).

Various sensors are used in site-specific management for mapping information about variability in the soil, topography, and crop (Stafford 2000). Some sensors use light reflected from the object of interest to provide information about the crop or soil-based spectral reflectance characteristics. Remote sensing detects the reflection of light by mounting sensors on remote platforms like airplanes, satellites, or on field equipment (proximal) (Stafford 2000). Mapping soil properties can include 'on-the-go' sensors that measure soil pH by using pH electrodes and soil organic matter by using optical sensors. Another 'on-the-go' sensor measures plant health by using spectral reflectance characteristics and applies fertilizer amounts based on relative plant health (Stafford 2000). Topography (e.g. slope, aspect, and depression) is measured spatially by using a digital elevation model (DEM). A DEM is created through aerial photography and GPS (Stafford 2000).

Yield monitoring systems measure yield through crop weight while harvesting the crop by using volume meters or impact sensors mounted on the combine that measure the interruption of light beam arrays or impact forces (Rains and Thomas 2000, McLoud et al. 2007). A GPS receiver on the combine captures the GPS coordinates for the field position at each point that yield was measured. The data are stored in the yield monitor, and a yield map is created by using mapping software that incorporates the GPS coordinates and site specific yield data (Rains and Thomas 2000).

GIS is computer software that stores, retrieves, and processes data. Data for individual fields are stored in layers that retain their spatial and temporal identification obtained via GPS (Rains and Thomas 2000). Analysis of data present across different data layers is done by using GIS software to create treatment maps or management options.

Variable rate technology (VRT) is site-specific management that changes the amount of inputs applied based on factor(s) of field variability. The technology to achieve variable rate application includes a treatment map and GPS or ‘on-the-go’ sensors and computer-controlled application equipment (Rains and Thomas 2000). The treatment map combined with GPS is used to relate the field position with treatments prescribed by the map, and variable rate application is achieved by computer-controlled equipment varying the rate based on the map recommendations. ‘On-the-go’ sensors vary application rates by communicating with the controllers when rates need to be changed (Rains and Thomas 2000). Figure 1.1 shows the two concepts of VRT. Current uses of VRT include seeding, fertilizer, lime, pesticides, and irrigation (Rains and Thomas 2000).

There are two approaches to site-specific management utilizing different technologies: map-based and sensor-based (Zhang et al. 2002, Krishna 2013). The map-based method utilizes technological tools of remote sensing, GPS, yield monitoring, and soil sampling. The steps for using the map approach for a field would include grid soil sampling, soil sample analysis at a laboratory, creation of a site-specific application map, and control of variable rate equipment utilizing the map with the aid of GPS to locate each position (Zhang et al. 2002).

Sensor-based approach utilizes 'on-the-go' sensors to detect soil and/or crop variability in real time; the measurements taken by the sensor controls the amount applied by variable rate equipment (Zhang et al. 2002). Integration of maps through GIS creates spatial databases using yield maps, soil sampling, remote sensing images, and other sensors. Analysis of temporal and spatial variation through geostatistics can be used to create crop models and/or treatment maps (Zhang et al. 2002).

The integration of information, decision support, and technology is fundamental to the cycle of site-specific management (Figure 1.2) (Stafford 2006). The start of the cycle is data collection at the appropriate temporal and spatial resolution. The data collection section of Figure 1.2 shows the soil and crop variability in the soil map, remote sensing imagery, and yield data. Data integration and analysis leads to the creation of management options, such as prescription development during the interpretation phase.

The application phase is the implementation of the management options that were determined from the previous phase (Stafford 2006, Krishna 2013).

Adoption of Site-Specific Management

Yield monitors have typically been the first step in adoption of site-specific management by farmers. Yield monitors were used on almost half of the corn and soybean acres in the U.S. in 2005-2006 used yield monitors; however, adoption of other technology has been slower (Schimmelpfennig and Ebel 2011). The use of variable rate technologies (VRT), such as pesticide and fertilizer applications, on acres in the Corn Belt was 16% in 2005. The adoption rate for VRT in the U.S. was 8% for soybeans and 12% for corn (Schimmelpfennig and Ebel 2011).

Interestingly, higher yields in soybeans and corn were documented for farmers that adopted GPS mapping and VRT compared to non-adopters (Schimmelpfennig and Ebel 2011). Adopters of yield monitors in the U.S. had significantly greater soybean and corn yields from 2001 to 2005. In addition, the average fuel consumption per acre was lower for farmers using yield monitors, VRT, and GPS maps in corn and soybean production (Schimmelpfennig and Ebel 2011).

Overview of Variable Rate Irrigation

Spatial variability in production agriculture affects profitability of operation mainly through the efficiency of inputs and their impact on yield. Site-specific management practices are used to help manage variability and increase overall yield. For example, the same amount of irrigation water may be applied differently across a specific field based on soil variables like texture, pH, and CEC. Variable rate irrigation (VRI) is a site specific water management tool that can be utilized to apply the optimal amount of water on all acres resulting in increased overall yields.

VRI is not only potentially beneficial to profitability, and it can also provide resource conservation benefits (Zhang et al. 2002). Water conservation occurs through programming the irrigation equipment to apply zero water amounts in areas with no crops (Sadler et al. 2005). Soil water holding capacity and water infiltration rates vary across fields as soil type and slopes change. Areas with decreased water infiltration rates and holding capacity lead to water runoff creating water waste, movement of sediment, and loss of nutrients (Sadler et al. 2005). Water runoff can lead to ponding in lower elevation areas of the field, and this can lead to anaerobic soil conditions, root damage, and eventually, damage to the whole plant (Sadler et al. 2005).

Soil and topographic variability in a field with uniform water application will lead to areas that are too dry and too wet (Sadler et al. 2005). Lighter texture (sandy) soils tend to dry out quicker due to a lower water holding capacity, and these soil types get under watered in uniform irrigation. Heavier (clay) soils have greater water holding capacity and do not drain as quickly and can get overwatered, leading to run-off (Evans et al. 2013).

VRI helps mitigate soil moisture and nutrient issues by taking into account the variability in the amount of water to apply to each area of the field (Sadler et al. 2005). Site-specific management is data and technology intense allowing farmers to make more informed water management decisions and better implementation of those decisions (Krishna 2013).

The potential exists for VRI to help improve irrigation efficiency and maximize water resources which is crucial in limited irrigation areas. Limited irrigation occurs when the amount of water that can be used on an irrigated field is restricted, and the crop's evapotranspiration (ET) demands are not satisfied (Schneekloth et al. 2009). These restrictions can be implemented for three reasons. The first reason is a decrease in surface water allocations from regional water transfers and/or droughts. Secondly, the irrigation well has reduced capacity because of the saturated aquifer having a limited depth. Finally, pumping restrictions may result in areas with declining groundwater levels (Schneekloth et al. 2009).

Pumping restrictions in the Great Plains due to declining groundwater levels have become prevalent. The Ogallala Aquifer provides groundwater for irrigated fields located in the High Plains (Johnson et al. 2011). The amount of water used from the aquifer for irrigation is not being recharged by precipitation at the rate it is being used. The declining aquifer has led to groundwater concerns and stricter regulations regarding the amount of water that can be used per irrigated acre (Norwood 2000, Johnson et al. 2011). Variable rate irrigation in this region can help mitigate issues with declining groundwater levels and water allocations by maximizing the efficient use of water resources.

VRI has a low adoption rate in the U.S., and approximately 200 center pivots and linear move sprinkler systems out of 175,000 are capable of implementing variable rate irrigation technology (Evans et al. 2013). A major barrier to adoption is the initial start-up cost of buying additional equipment and controllers needed for VRI (Lu et al. 2005). Another barrier is the lack of knowledge and expertise for those involved in the technology, e.g. growers, technicians, and dealers. Increased training is necessary to improve management skills required by the added complexity of the VRI system (Evans and King 2012). Management levels, costs, and water productivity changes as VRI technology complexity increases (Figure 1.3).

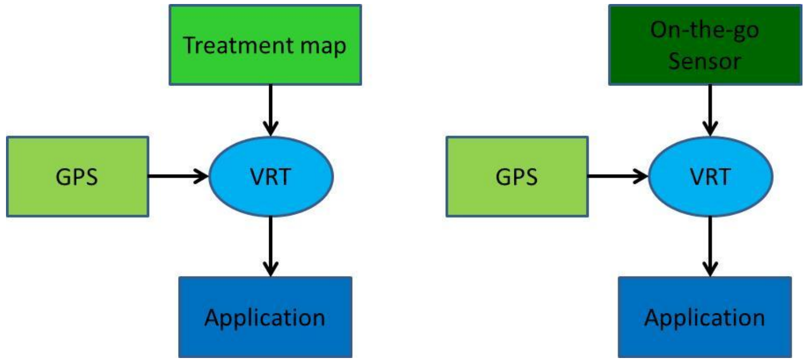

Figure 1.1. The difference between the components involved in the two concepts of variable rate technology. Source: Rains and Thomas (2000).

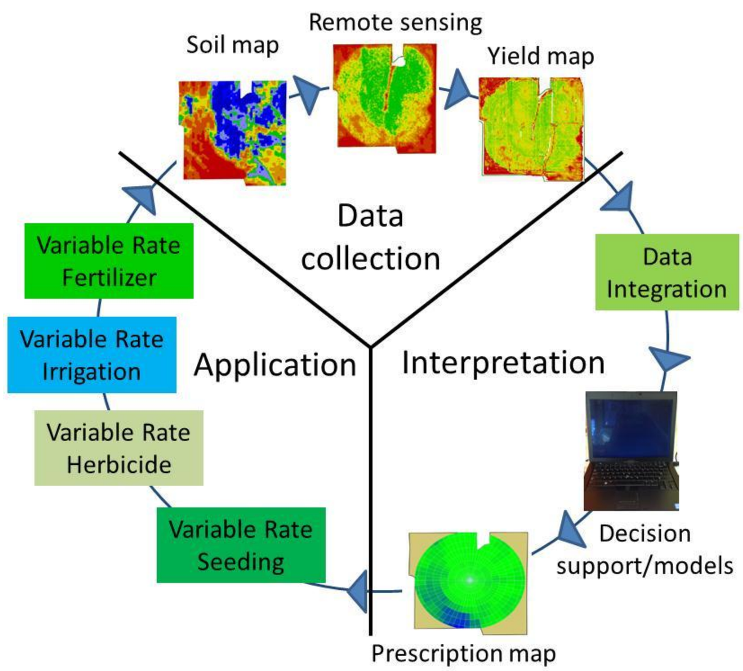

Figure 1.2. The cycle of site-specific management with its components of information, decision support, and technology. Source: Stafford (2006).

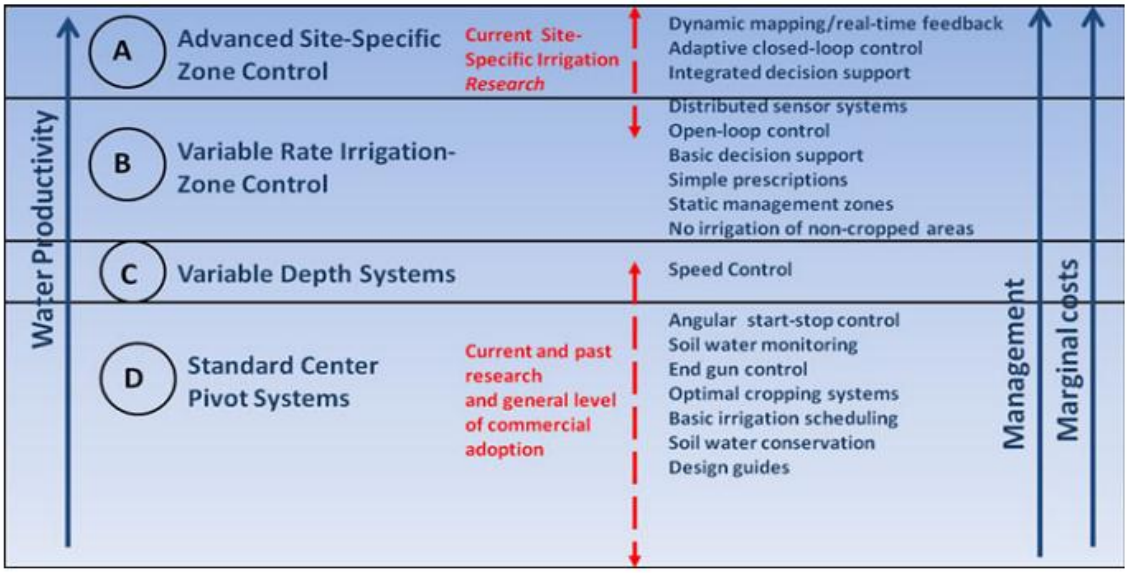

Figure 1.3. Changes associated with utilizing different variable rate irrigation systems. Source: Evans et al. (2013). Used by permission.

CHAPTER 2

SYSTEMS OF SITE-SPECIFIC WATER TECHNOLOGY

Irrigation System Types

Irrigation systems are used as a temporal supplement to the amount of water received from annual and seasonal rainfall. The types of irrigation systems differ mainly based on their purpose and scale of use (Ali 2011, Evans and Sadler 2013). The irrigation system most suitable for an operation depends on the crops being cultivated, physical characteristics of the site, quantity and quality of available water, and management ability. Classification of irrigation methods varies based on water pressure or energy required for application, position of water application relative to soil surface, or area wetted by irrigation (Ali 2011).

Pressure requirement classification contains two groups of irrigation methods: gravity and pressurized. Gravity or surface irrigation relies on gravity to distribute water throughout the field. Pressurized irrigation uses pressure to pump and distribute water throughout the field using tubing or pipes (Ali 2011). The mode of application further divides both groups into subgroups. Gravity irrigation can be accomplished through border, basin, and furrow irrigation. Pressurized irrigation systems include drip or microirrigation and sprinkler irrigation (Ali 2011).

Surface or gravity irrigation is the most common method of applying water to fields in the world, with 95 percent of irrigated land using surface irrigation (Evans and Sadler 2013). Gravity irrigation systems have the lowest cost, but they are the most inefficient and have the highest labor costs compared to other irrigation. The inefficiency is due to water application on the soil surface causing variable infiltration rates due to different soil characteristics, inflow rates, and slope across the field (Evans and Sadler 2013).

Microirrigation includes the use of microsprinklers and drip emitters. Systems can be permanent or temporary and buried or placed on the soil surface (Evans and Sadler 2013). Microirrigation is the most efficient irrigation form since irrigation occurs in smaller quantities with more frequent water applications providing a balance of soil water and aeration to the roots (Evans and Sadler 2013).

Sprinkler irrigation systems include wheel-move and hand-move laterals, self-propelled or continuous-move systems like center pivots and linear moves (Evans and Sadler 2013). Center pivot systems irrigate fields in a whole circle or circle segments by rotating around the pivot or center point, typically located in the field center, creating dryland corners (Evans and Sadler 2013). Linear move systems use a physical guidance system, like GPS, to irrigate fields that are square or rectangular. Center pivots have lower labor costs due to lower management needs compared to linear move (Evans and Sadler 2013).

Center pivot irrigation systems are composed of towers or motorized structures containing wheels and the towers are linked by a lateral pipeline containing sprinklers. A span is the unit between two towers with the average length being 98 to 230 feet (Evans and Sadler 2013). The self-propelled, motorized nature of the towers allows the lateral to rotate around the center point. The center pivot can make one complete circle in a time period of a half a day to multiple days depending on the speed (Ali 2011). The application depth is controlled by the moving or ‘walking’ speed of the towers (Evans and Sadler 2013).

The number of towers and lateral length is determined by the field size with one center pivot capable of irrigating a 12 to 494 acre field (Evans and Sadler 2013). Longer laterals mean that the end must travel faster to irrigate the larger area and keep uniform water application. There are more nozzles as the distance from the center point increases with same amount of pressure. The greater number of nozzles on the end span allows the same amount of water to be applied at an increased speed. The difference in speed allows the first span and the last span to be watering the same radial location or for all the spans to be in line with each other (Ali 2011).

The benefits of center pivot systems are less labor costs due to greater automation, more uniform and efficient water application, and ability to cover larger areas. Both gravity and pressurized systems are capable of some form of site-specific water application depending on the environment (Evans and Sadler 2013); however, the focus here will be on center pivot irrigation systems.

VRI Control Systems

Travel speed of center pivots determines the water application depth; whereas, the sprinkler package controls the base uniformity and rate of application. Control panels consisting of a slow-down timer and a control box on each tower were implemented in 1980s by center pivot companies to control the speed of the machine (Evans et al. 2013). The lateral travel speed could be adjusted across large field sectors of 30 to 180 degrees.

The capability of pivot speed changes were marketed by Valmont Industries in 1992 and achieved by the angle resolver and panel programming (Evans et al. 2013).

An angle resolver is located at the center point to document the pivot's angular position. There are errors associated with the angle resolver with one being the instrument deteriorating over time due to metal rubbing on metal. Location errors can be up to five degrees which equates to 98 feet for a 1280-foot lateral (Kranz et al. 2012). Another limitation is the instrument only detects the first tower's position; thus, the location of the first tower may not compare to the place of the end tower. A Wide-Area Augmentation System (WAAS) GPS is currently in use to correct errors of the angle resolver (Kranz et al. 2012). It utilizes a GPS antenna to determine the location of the end tower within 10 feet. Lateral position within the field is important to VRI for determining management zone locations and decreasing water misapplication (Kranz et al. 2012).

More developments in control technologies include stopping the pivot based on field location or at the circle completion point, multiple speed adjustments during irrigation, and switching end guns on and off (Kranz et al. 2012). Pivot control panels in recent years allow the travel speed to change in sector areas ranging from 1 to 10 degrees as it revolves around the field. This allows application depths to change based on the sector degree size specified in the VRI prescription. This is referred to as sector or speed control (Kranz et al. 2012).

A sector control system has constant water flow and varies the speed that the pivot moves in each sector or pie wedge, with faster speeds reducing application rate and slower speeding increasing application rate (Perry and Pocknee 2003). Pivot speed typically changes every 6 degrees allowing 60 slices in a pivot, or at the most 1 degree giving 360 slices. Figure 2.1 shows water application using a sector control VRI pivot system. One limitation with speed control VRI systems is variability does not typically follow long and narrow pie wedged areas in the field. Water control through machine speed may not account for enough field variability observed in the radial distribution pattern (Kranz et al. 2012).

Zone control irrigation allows the pie wedges to be further broken into smaller zones, potentially creating over 5,000 management zones in a field. Water application varies per management zone through pulse modulation (Kranz et al. 2012). The pulse rate of the sprinkler control valve can vary in each management zone, allowing the application depth to change. Sprinkler nozzles or groups of nozzles cycle off and on for a certain center pivot speed with a gradual transitional change between one management zone to the next (Kranz et al. 2012). Water application is controlled by output amounts of each groups of sprinklers based on the field position as determined by the prescription (Figure 2.2) (Evans et al. 2013).

Sprinkler control on zone control irrigation can be accomplished as blocks or individually and is typically dependent on management zones. Block controlled sprinklers are usually grouped with three to five sprinklers and limits management zone numbers in a field (Kranz et al. 2012). The block is installed at the same time as the irrigation plumbing, but because a prescription would control the entire the block, the block may water across more than one management zone at the same location. Each sprinkler is wired to a relay box, and the number of control boxes varies based on how many nozzles are in each block. There is a relay box for each nozzle in individual controlled sprinklers. Individual sprinklers can be controlled separately, and thus, prescriptions can be made more specific rather than being tied to a block. This design alleviates the limitation of a nozzle block irrigating more than one management zone at a single location. (Kranz et al. 2012).

Components of VRI Control System

A VRI control system is needed on center pivots to use variable rate technology. Sector control systems consist of a VRI panel with telemetry. A new panel may not be needed as speed control is a standard part of most panels with automated controls (Valmount Industries 2013); however, the equipment may need a software upgrade before it can be used for VRI. VRI prescriptions can be uploaded or programmed into the control panel. Telemetry communication enables remote prescription uploads (Valmount Industries 2013) and provides access to the control panel from a computer, smart phone, and/or tablet/iPad (AgSense 2012). Application-specific software in the control panel utilizes a wireless network with an annual subscription fee. The internet connection with the unit provides in-field sensor readings and remote monitoring of the pivot (Kranz et al. 2012). Providers of telemetry products include Valley and AgSense, and these products work on pivots made by T&L Irrigation, Zimmatic, Valley, and Reinke (AgSense 2012, Valmount Industries 2013).

Zone control systems may require a new control panel, as some of the standard panels are not equipped for zone control (Evans et al. 2013). For example, VRI zone control using Valley irrigation systems requires a Valley Pro2 control panel, which is one of six control panels offered by Valley. Additional essential hardware includes sprinkler valves that are controlled independently (Valmount Industries 2013). These valves are used at every block of sprinkler heads or at every sprinkler head, depending on the degree of zone control desired (Evans and Sadler 2013).

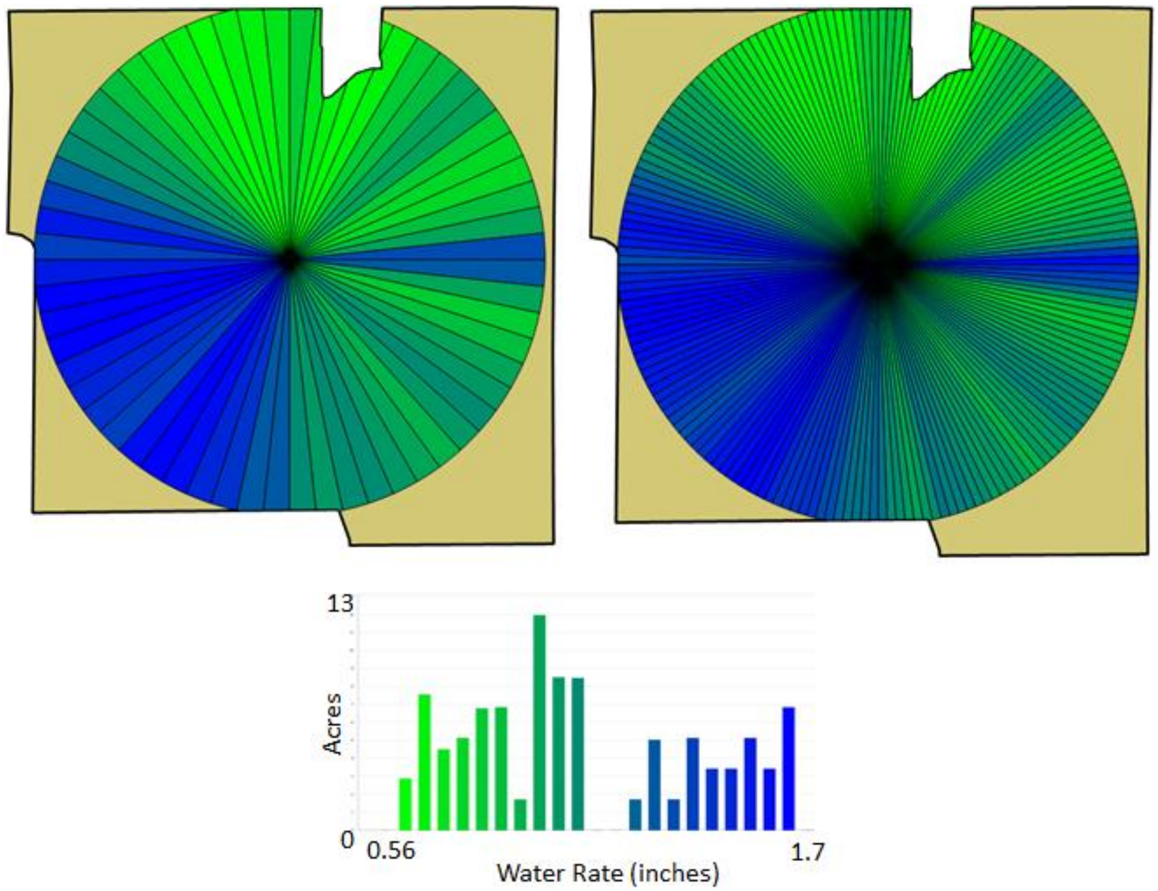

Figure 2.1. The VRI prescription is built for a sector control system. The prescription on the left is built for 6 degree sectors allowing 60 slices in a pivot whereas the one on the right is 2 degree sectors with 180 slices. Figures are courtesy of DuPont Pioneer.

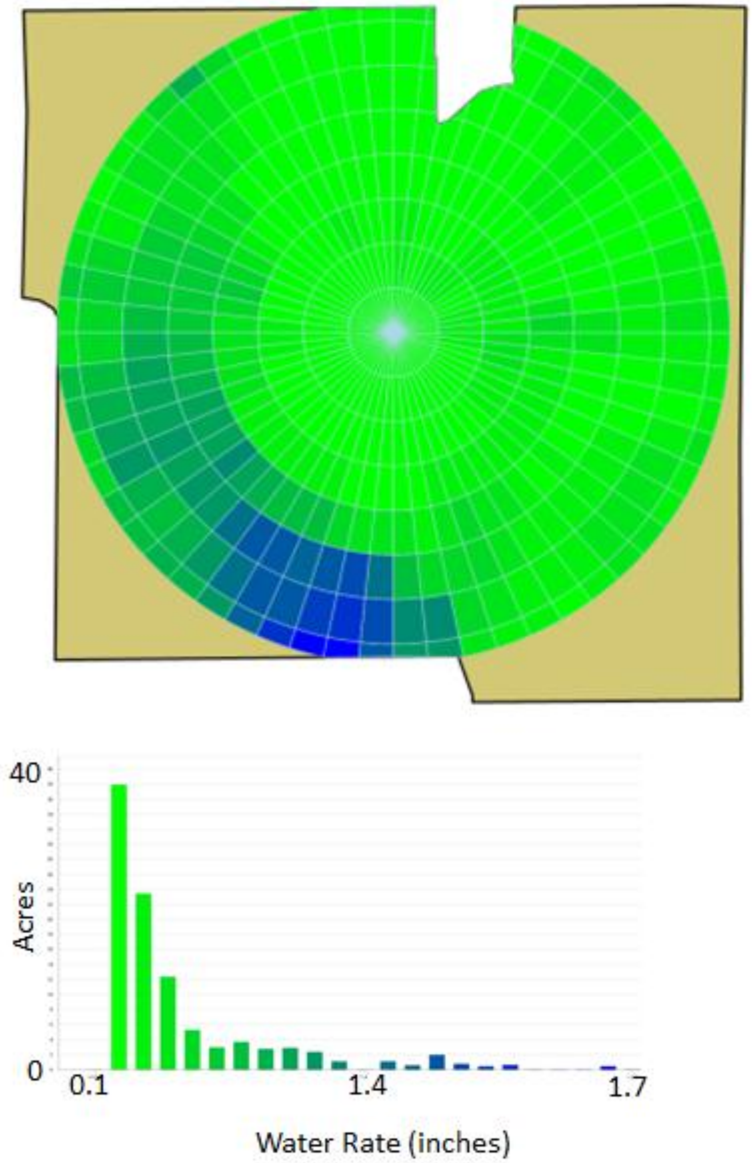

Figure 2.2. The VRI prescription is built for a zone control system. Figures are courtesy of DuPont Pioneer.

CHAPTER 3

FIELD VARIABILITY AND MANAGEMENT ZONES

Field Variability

Most crop production fields are heterogeneous due to the presence of natural variation, e.g. soil type, topography. Variability in production agriculture affects profitability mainly through yield impacts and inefficiency of inputs. This can translate into profit or loss for producers depending on the economic environment. Production inputs and outputs determine profits or total cost and total revenue. Practices are used to manage variability and increase yield. For example, more or less water may be applied based on soil variables like texture, pH, and cation exchange capacity (CEC). Temporal and spatial variables impacting production include yield, field, soil, anomalies, management, and crop (Zhang et al. 2002).

Historical and current fluctuations of crop yield throughout a field is one way to measure yield variability. Temporal and spatial yield fluctuation in a field is typically indicative of other sources of variability either known or unknown (Zhang et al. 2002). Field variability refers to the topography of the field, such as aspect, slope, elevation, and terrace. Soil variables include soil fertility, physical characteristics, chemical properties, hydraulic conductivity, water holding capacity, and soil depth (Zhang et al. 2002). Physical properties of a soil include texture, moisture content, electric conductivity, density, and mechanical strength. Soil chemical properties refer to pH, CEC, and salinity (Zhang et al. 2002).

Another production variable includes anomalies such as pest infestation and/or pathogen infections. Management variability refers to differences in tillage, hybrids, plant population, fertilizer and pesticide application, or irrigation (Zhang et al. 2002). The patterns of spatial variation in crop yields are greatly influenced by the temporal variation from climate fluctuations (e.g. rainfall) that occurred during that year (Schepers et al. 2004).

Crop variability includes biophysical properties, grain quality, plant density and height, nutrient and water stress, and leaf chlorophyll content (Zhang et al. 2002). There are many potential sources of variability within one field, and it is important to determine and measure the factors that have the most direct effect on the relationship between the input and crop yield (Doerge 1998). This paper will refer to field variability but because of the focus on irrigation, most of this variability results from soil and field differences as described by Zhang et al. (2002).

Measuring Field Variability

The measurement of field variability is important in defining the sources of the variability as well as creating management zones to manage the variability. One primary technique to measuring spatial variability is to measure topography by using DEM (Stafford 2000, Schepers et al. 2004). Topography is important in determining places of water run-off that can lead to overwatering low areas and under watering high elevation areas (Sadler et al. 2005).

Yield maps generated by yield monitors at harvest are another method to measure field variability. However, a weakness to yield mapping is that yield typically varies spatially from year to year, incorporating random or unexplained variability. One way to overcome this is through classification of regions into high, medium, and low yields (Schepers et al. 2004). Another way to increase the robustness of using yield to measure variability is using yield maps from multiple years. Multi-year yield analysis combines yield data from several years into one layer to observe spatial trends across multiple years (Shanahan and Gunzenhauser 2011).

Remote sensing, such as satellite imagery, can be used to measure crop variability and provide an indirect measure of field variability. Information from remote sensing is valuable as the ‘crop is the best sensor of its own environment’ (Stafford 2000). The imagery provides a measure of relative plant health and indirectly the environmental factors affecting plant health. Thus, these measurements give guidance on the efficient application of inputs (Stafford 2000).

Soil property measurements, such as electrical conductivity (EC), are used to define variability within a field. Electrical conductivity measures the electrical current that a soil can conduct, and it is another way to indirectly measure other soil properties that affect plant health and ultimately grain yield (Gunzenhauser et al. 2012).

EC provides variability estimates pertaining to soil characteristics of water holding capacity, texture, CEC, drainage, subsoil properties, and salinity (Kitchen et al. 2003, Grisso et al. 2009). Shallow or topsoil electrical conductivity measurements are taken at depths of 0-12 inches, and deep or subsoil EC is measured at 0-36 inches. On-the-go soil sensors with the aid of GPS are able to map soil electrical conductivity (Stafford 2000).

Mapping soil EC is an indirect measurement of soil variables that are useful in quantifying difficult characteristics like soil moisture content. There are two companies offering commercial EC measurement services: Veris Technologies and Geonics Ltd (Stafford 2000). Veris Technologies utilizes coulters that penetrate into the soil providing a direct contact method to measure soil conductivity. Electrical current is passed through the soil using a pair of coulter-electrodes that measures the drop in EC for the two soil depths (Veris Technology 2013).

The EC signal is influenced by soil properties such as soil moisture and texture. Clay soil is more conductive due to greater particle-to-particle contact and water holding capacity (Veris Technology 2013). Sandy soils have lower particle-to-particle contact and water holding capacity leading to lower conductivity. Soil moisture affects EC mapping; however, the soil EC readings have the similar patterns no matter the soil moisture content (Veris Technology 2013). Genomics Ltd uses an indirect method to measure EC through a non-contact electromagnetic induction probe (Stafford 2000). Deep EC measurements (Figure 3.1) are used to measure the variations in soil water holding capacity and aid in creating management zones and a VRI prescription.

Defining Management Zones

Variability can be managed through site-specific technologies by dividing a field into smaller areas called management zones (Doerge 1998, Zhang et al. 2002). Each management zone is an area in the field with similar yield-limiting factors, and rates can be changed to increase yield and optimize inputs (Doerge 1998). For example, management zones created for crop irrigation typically use site characteristics such as topography, soil organic matter, soil texture, and yield zones (Doerge 1998).

There are several factors to take into consideration when determining the field variables to use in creating management zones. The factors that have the most direct effect on the relationship between the input and crop yield, should be used in defining management zones. These factors should be directly correlated (Doerge 1998). The data used for defining management zones needs to be quantitative. Some data needs to be repeatable like yield maps, which are more robust after combining several years. There are some field variables that are stable over time and need only be measured once, e.g. EC (Doerge 1998). An EC map is useful for an infinite time period as long as no major soil disturbance occurs in a field.

The density of data points is an important consideration as fewer sampling points will increase interpolation and reduce the accuracy in defining management zones. Cost to collect or acquire the spatial data may be a hindrance to implementing management zones; however, some information sources are free or less expensive, such as the USDA soil survey (Doerge 1998). The spatial scale of data collection should be comparable to the scale that will be used for defining management zones. Another consideration of scale is the degree of spatial variability for a field. For example, does the variability change within a few feet or miles (Doerge 1998).

The development of management zones should consider the scale of the implement being used to apply the input. In some cases, the scale of the management zones is coarser than the scale used to measure the field variability. Irrigation management zones or VRI prescriptions are limited by the ability of the center pivot to change water application rates. The deep EC measurements are taken at a finer scale or resolution than current capabilities of the center pivot and VRI prescriptions. Typically, site specific applications of pesticides and fertilizers have a finer management zone resolution (John Shanahan, personal communication).

A strategy for defining management zone can be developed using a three step process. The first step is to start simple by utilizing field variability factors with easily accessible data that are highly correlated to crop yield (Doerge 1998). The best data are typically stable over time, densely sampled, and quantitative. Improved precision of management zones can occur over time by adding more factors that affect field variation and crop yield (Doerge 1998). For example, including multiple years of yield maps, aerial images, and/or spectral reflectance of the crop canopy will refine the management zones. Evaluation of the management zone strategy is the final phase of the process. On-farm testing techniques can be used to determine the effectiveness of the management zones and what changes need to be implemented to improve the strategy for defining the zones (Doerge 1998).

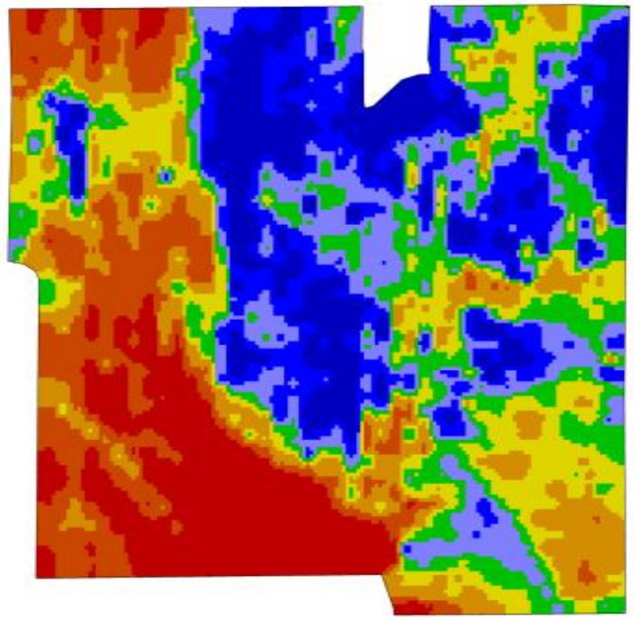

Figure 3.1. An electrical conductivity map showing the variability that occurs within a field. Figure is courtesy of DuPont Pioneer.

CHAPTER 4

BUILDING A VRI PRESCRIPTION LAYER

VRI application rates and ranges can vary depending on the EC values of the field (CropMetrics 2013). After EC data have been collected, the data are imported and processed into a layer in geographic information systems (GIS) software (LaRue and Evans 2012). EC data are analyzed to create a VRI prescription, and after the prescription is built, adjustments for the forecasted crop water use can be made. The prescription is exported to the irrigation control system.

Geographic Information System

The value of GIS is evident wherever geographic location is an important factor in data collection, storage, processing, and analysis (Ali 2011). Input data sources for GIS include mainly remote sensing and GPS based applications. GPS data are structured in a vector format or as a sequence of points, lines, or polygons; whereas, a raster format is used for remote sensing data (Ali 2011). Raster data are formatted in a grid with each cell containing data regarding the location and attribute value (Brase 2006). The X, Y coordinate system is used to store the spatial data in the GIS database. Multiple methods are used to input data into the GIS software (Ali 2011).

One data entry system used for inputting data into GIS is keyboard entry where attributed data are manually entered into the layer. A coordinate geometry procedure inputs spatial data by calculation and entry of coordinates, and is typically used for entering land record data (Ali 2011). Scanning or scan digitizing can be used to enter map data by converting analog data, such as a printed map, into digital format. Manual digitizing is most commonly used for spatial data entry from maps. The digitizer converts a source of analog spatial data to digital data containing a vector structure (Ali 2011).

The GIS software contains two components, the map and database, that provide functionality for storage, processing, and analysis of data (Brase 2006). The map component is comprised of spatial coordinates to represent objects through a visual representation of the data. This includes the use of many map layered together (Brase 2006). One map can have up to a thousand features that provide the digital representation of an object in a map format. The GIS map view window allows these different features to be viewed in each layer within a stack of multiple map layers (Brase 2006).

The database component stores spatial and attribute data for each object or feature represented in the map. Attribute data provides information about each feature (Brase 2006). A database is essential due to the potential for a large amount of data in a layer as each feature may have many attributed data categories for each feature in a map (Brase 2006).

The attributed data is typically stored in a spreadsheet form with each feature having its own row. Each column is an attribute or information category that contains a value for each feature, and columns are called fields (Brase 2006). For example, each feature may have four fields: the amount of water applied by the center pivot, rain water, base application rate, and the yield. The database is able to organize, store, retrieve, and analyze the data (Brase 2006).

There are multiple functions of GIS software that contribute to its effectiveness as a data analysis tool. Data manipulation is used to transform data into a form that is usable or functional for analysis (Brase 2006). For example, it is necessary to transform data to the same resolution or scale before layers can be integrated (Ali 2011). Data layers can be integrated during data manipulation by utilizing the join feature (Brase 2006).

The table join feature integrates non-geo-referenced (aspatial data) and geo-referenced layers together. The table join between two layers requires that the two layers have at least one attribute in common (Brase 2006). Spatial data do not contain a spatial reference and are not connected to a map feature (Brase 2006). One example of spatial data is soil test results. A table join can be used to link soil sampling points on a map created by GPS and the aspatial data of soil test results. The soil test results are the source database to be joined to the sampling points destination database, resulting in a map of the test results (Brase 2006).

A spatial join integrates two layers based on common location instead of common attribute. The source database is typically a polygon feature; whereas, the destination database is a point feature (Brase 2006). This occurs when joining a yield map layer containing point data to a soil type layer with polygons of soil types (Brase 2006). Data search within GIS occurs after preparation of the database by manipulation.

The large amount of data within GIS can be selectively accessed through the use of data retrieval. The most common way to retrieve data is by querying the database for a selected attribute within the context of GIS (Brase 2006). Spatial location, also called a spatial extent can be queried within a map to determine events or objects of interest and distance between objects (Brase 2006).

After data manipulation and retrieval, data analysis is used to build relationships between data layers. One form of data analysis in GIS is modeling through the use of rules or criterion (Ali 2011). The ability to overlay data layers provides the flexibility to observe spatial interactions in the model's parameters as well as display the results in a spatial form or a map layer. The decision support system is one type of GIS model that creates rules for individual layers. The lumped parameter model connects the layers using equations, shows the relationship between the parameters, and provides an output (Ali 2011).

Current Status of GIS Software for VRI Applications

CropMetrics is the only provider of GIS software that writes VRI prescriptions. The Virtual Agronomist tool from CropMetrics™ processes geo-referenced spatial EC and topography data to create data layers that are analyzed through the use of an algorithm to create a sector or zone control VRI prescription (LaRue and Evans 2012, CropMetrics 2013).

Providers of telemetry products (e.g. Valley and AgSense) and pivots (e.g. T&L Irrigation, Zimmatic, Valley, and Reinke) allow users to write their own VRI prescription (AgSense 2012, Valmount Industries 2013). The telemetry and pivot providers do not provide a GIS software program to process and analyze the spatial data to create the VRI prescription. The user needs to process and analyze the data by using a GIS software program and manually enter in the application rate for each management zone such as sector or zone (AgSense 2012).

Figure 4.1 illustrates the differences between Virtual Agronomist and manually entering the base application amount. Generally, a VRI prescription is built using a base application rate of 1 inch. The amount of water that is applied varies from the base application rate depending on the variation of the field characteristics present in each management zone (CropMetrics 2013).

Irrigation scheduling may call for a different application rate than 1 inch during the growing season depending on crop water needs (CropMetrics 2013). If necessary, the base application could be reduced to 0.75 inches by increasing the pivot speed. Irrigation scheduling may call for more water to be applied, and the base could be increased to 1.5 inches by slowing the pivot speed. If these changes are made, the VRI prescription is adjusted without building a new prescription (CropMetrics 2013). The Virtual Agronomist has an interface where the user can input and change the base application rate. The prescription automatically adjusts a new output when changing the rate without building a new prescription. Table 4.1 shows adjustments of the 0-30 degrees of a prescription based on 6 degree increments.

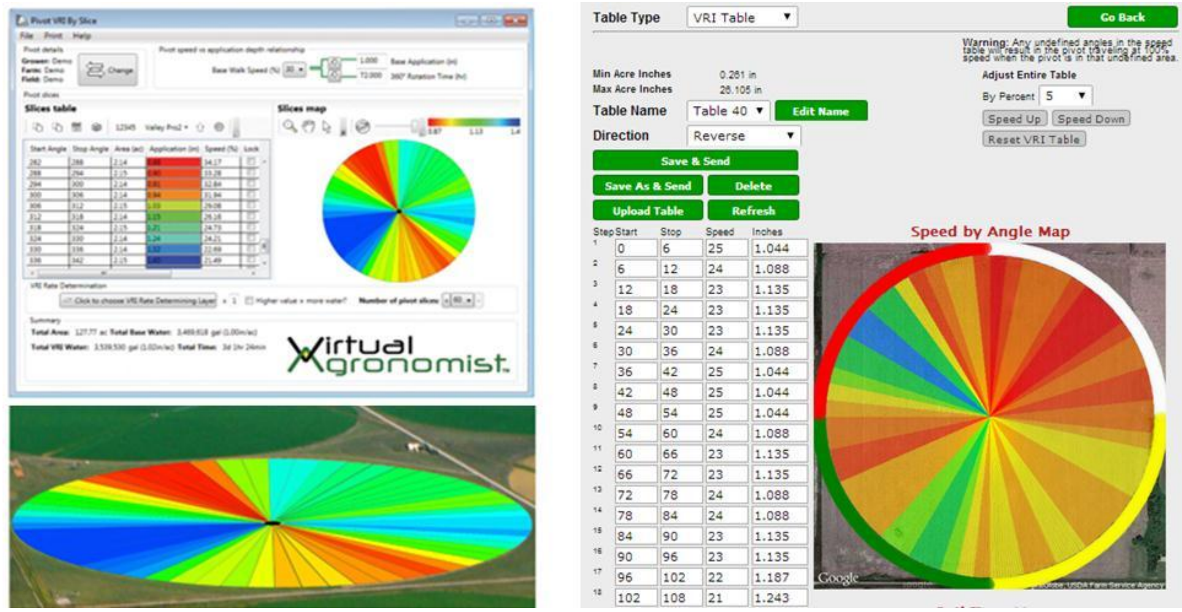

Figure 4.1. Virtual Agronomist from CropMetricsTM used to write a VRI prescription (left) and manual entry of application rate for each sector using AgSense WagNet (right). The prescription from Virtual Agronomist can be exported into AgSense WagNet account using the upload table button and remotely uploaded to the center pivot panel. Figures are courtesy of CropMetrics™ and AgSense.

Table 4.1. The changes in the VRI prescription due to varying the base application rate. The speed of the pivot in this example alters the inches applied. Table is courtesy of DuPont Pioneer.

Angle		0.75" Base Application		1" Base Application		1.5" Base Application	
Start	Stop	Speed	Inches	Speed	Inches	Speed	Inches
0	6	21	0.757	17	0.935	9	1.767
6	12	20	0.795	16	0.994	8	1.988
12	18	19	0.837	15	1.06	8	1.988
18	24	18	0.883	14	1.136	7	2.272
24	30	20	0.795	16	0.994	8	1.988

CHAPTER 5

SOIL WATER MANAGEMENT

Evapotranspiration

Water is essential for corn production and adequate water at critical times during the growing season can significantly increase yields. Irrigated corn fields have a 30% increase in yields compared to non-irrigated fields (USDA National Agricultural Statistics Service 2007). Irrigation is an input used on 15% of total US corn acres, but it contributes 20% to total US corn production (USDA National Agricultural Statistics Service 2007). Irrigation is implemented to supplement lack of precipitation and depletion in the soil water level in order to maintain crop evapotranspiration and productivity (Phene et al. 1990).

Irrigation improves production due to a positive, linear relationship between grain yield and total seasonal crop water use or evapotranspiration (ET). Figure 5.1 summarizes results from growers' fields across south-central Nebraska that illustrate the linear relationship between grain yield and ET (Grassini et al. 2009). Evapotranspiration is a measure of how corn utilizes and loses water. The system loses water through evaporation from the soil and plant surfaces and transpiration through the plant (Shanahan and Groeteke 2011).

Irrigation timing is important because water is essential at critical times during the growing season to achieve maximum yield and increase profitability on an operation. Figure 5.2 shows how different corn crop growth stages respond to water stress with yield being dramatically decreased during the reproductive stages (Sudar et al. 1981, Shanahan and Groeteke 2011). Vegetative stages are more tolerant of water stress due to a reduced water demand.

Soil Water Concepts

Soil water is the water that moves through or stored within the soil profile, and it is important to plant growth and yield (Phene et al. 1990). Plant water potential is a way to measure the direct influence of soil water on plant growth, and this indirectly impacts plant temperature regulation, nutrient transport and uptake, and soil aeration. Plants serve as one conduit for water movement from the soil to the atmosphere (Phene et al. 1990).

Transpiration is the loss of water vapor from the stomata, and it is defined by the total leaf conductance multiplied by the leaf to air vapor pressure deficit. Stomatal conductance is the extent to which a plant opens its stomata (Taiz and Zeiger 2010). Transpiration is the mechanism that plants use to move water from the soil to the roots through the plant and out into the atmosphere. High water loss can occur through transpiration. It also serves as a way for a plant to lower its temperature through evaporative cooling of transpired moisture before reaching lethal temperature levels (Taiz and Zeiger 2010).

An increase in temperature and low relative humidity increases the amount of evaporation of water from the soil surface. Soil evaporation also increases with exposed surface, fine textured soil, and a shallow water table. Evaporation from the soil decreases the amount of water available to the plant (Taiz and Zeiger 2010).

Soil water is measured either by water content or water potential. Soil water content is the amount of water present in the soil, and it is measured by a mass or volume fraction (Phene et al. 1990). Soil water content does not measure water movement in the soil profile or plant available water (Phene et al. 1990). Soil water potential compares a standard reference to the soil water energy status. Water moves through a system from areas of high water potential (less negative) to areas of low potential (more negative) (Taiz and Zeiger 2010). Soil water potential does not measure the amount of root zone water, but it measures the plant available water in the soil profile (Phene et al. 1990).

The driver of water movement through the plant is transpiration (Taiz and Zeiger 2010). The soil has a less negative water potential than the roots, which is less negative than leaves, and leaves are at a lower water potential than the air. Therefore, leaf vapor pressure deficit (VPD_{leaf}) is the driver of water movement through the plant by creating a pressure deficit gradient between the air and the leaf (Taiz and Zeiger 2010).

The driving force of soil water movement, also called mass flow or convection, is water potential. Soil water potential is determined by matric potential, osmotic potential, and gravitational potential (Taiz and Zeiger 2010). Matric potential is the attraction of water to soil particles. A more negative matric potential occurs in soils with low soil water content as the water is more attracted to the soil particles. Plant available water is the range between field capacity and permanent wilting point (Taiz and Zeiger 2010). At the permanent wilting point water, the negative matric potential prevents plants from accessing soil water.

Water potentials, specifically osmotic and pressure potentials, are important to plant form and function (Taiz and Zeiger 2010). Pressure potential or turgor pressure is the physical force exerted by the cell wall that presses on the water in the plant cell, trying to drive water out of the cell (Taiz and Zeiger 2010). Pressure potential is important in cell expansion since it is physical force that applies pressure to the cell wall. The chemical potential exerted on water due to solutes being present is called osmotic potential. Water stress resulting in wilting is due to a decrease in turgor pressure (Taiz and Zeiger 2010).

Plant nutrient uptake is affected by the amount of soil water, soil characteristics, and soil microbial activity. The amount of water in the soil pores influences the movement of solutes in the soil through diffusion and convection to the plant root (Taiz and Zeiger 2010). The buffering power of the soil gives an indication of how a solute will interact with the solid phase. Soil with a high buffering power has a lower effective diffusive coefficient and a slower diffusion rate, affecting the nutrient supply and transport to the root (Taiz and Zeiger 2010).

The soil texture greatly influences the pore spacing and water content of a soil, cation exchange capacity (CEC), specific adsorption and desorption of cations and anions, and buffering power (Taiz and Zeiger 2010). Sandy soils typically have no negative charge on the internal lattice or structure resulting in little to no buffering power, and theoretically, all solutes should stay in solution. Water and solutes in the soil solution leach quickly in sandy soils due to the large pore size (Taiz and Zeiger 2010). Clay soils have a negative charge on the mineral lattice, creating CEC and increasing buffering power, attracting solutes to the soil solids. Clay particles have smaller pores and a higher water holding capacity (Taiz and Zeiger 2010).

Plant uptake of nutrients, or sink size, is a function of root surface area, root length density, root absorbing power, and soil solution concentration. Net convective flux is the driving force of water and dissolved solute movement to the root surface (Taiz and Zeiger 2010). The amount of water and nutrients taken up by the plant is determined by net convective flux to the root and transpiration rate. Nutrient movement into and within the plant occurs with water movement (Taiz and Zeiger 2010).

Another key factor in plant nutrient availability is soil microbial activity. Soil microbial activity is essential to nutrient cycling as soil microorganisms can immobilize soil nutrients (Robertson and Groffman 2006, Plante 2006). This indicates that fertilizer inputs may not be readily available to plants. Soil microorganisms stimulate the turnover of the microbial biomass to mineralize nutrients that are then able to be taken up by the plant (Plante 2006, Robertson and Groffman 2006).

The amount of water in the soil pores also affects the availability of substrates needed for soil microbial activity that results in the release of plant available nutrients. Microorganisms need a film of water around the substrate to access the substrate (Robertson and Groffman 2006). Water is needed for pore connectivity, solute diffusion, and microbial movement and activity. However, some microbes need oxygen, and the amount of soil water influences the amount of oxygen present. Therefore, a soil can be water or aeration limiting for a soil microorganism as well as for plant roots, reducing their activity (Robertson and Groffman 2006).

Soil Water Measurements

Crop water management utilizes soil water measurements to make decisions about irrigation scheduling (Werner 2002). VRI prescription changes the spatial distribution of water applied, and is built using a base application rate determined by the target rate that a grower typically applies for a given field. The decision about the total seasonal irrigation amount and when to apply can be determined by several methods including the feel and appearance of the soil, measurement of soil water content, and/or soil water potential (Phene et al. 1990).

The feel method starts with collecting soil samples from varying depths by using a soil probe. Each soil sample is sectioned into smaller samples to determine how well the soil can be formed into a ball or ribbon using your hand and fingers (University of Nebraska-Lincoln 2012). The wetness of the soil is estimated from the cohesiveness of the soil ball. Another characteristic to observe is if a finger imprint occurs after squeezing the ball. Soil water content is estimated by using a guide and the characteristics noted above (University of Nebraska-Lincoln 2012).

Soil water content can be measured by direct and indirect methods. The direct or gravimetric method extracts water, typically by using an oven to dry the soil, and the volume or mass of the extracted water is measured (Phene et al. 1990). The water content is a ratio of mass or volume of water present to the total weight or volume of the soil sample.

Indirect methods include neutron probe and capacitance or time domain reflectometry (TDR) (Jones 2004). A neutron probe detects hydrogen in the soil water and gives a measurement of soil water content. The probe utilizes a radioactive source that is installed in the soil through an access tube (Werner 2002). Neutrons scatter or slow down their movement in the presence of water molecules due to the hydrogen nucleus (Phene et al. 1990). The number of neutrons reflected by soil hydrogen is measured by a counter, and this is used to calculate soil water content (Werner 2002).

Time domain reflectometry measures the dielectic constant of the soil which fluctuates in response to changes in soil water content (Werner 2002). An electrical signal is sent through the soil along the instrument's two parallel rods, and the travel time of the wave is recorded by an electronic meter. Travel time of the wave is related to soil water content as the wave travels slower in wet soil than in dry soil (Werner 2002). The reflected electrical signals provide the soil water content as a percentage over the length of the rod or at multiple depths.

Soil water potential can be measured by psychrometers, tensiometers, and electrical resistance measurements. A psychrometer directly measures total soil water potential by depressions in the vapor pressure during equilibrium of the vapor and liquid phases (Phene et al. 1990). The tensiometer directly measures soil matric potential, and electrical resistance blocks or gypsum blocks measure soil matric potential through soil moisture tension (Phene et al. 1990). Water is absorbed from the soil by the probe's block material (e.g. gypsum). Water in the block is measured using electrical probes (Werner 2002).

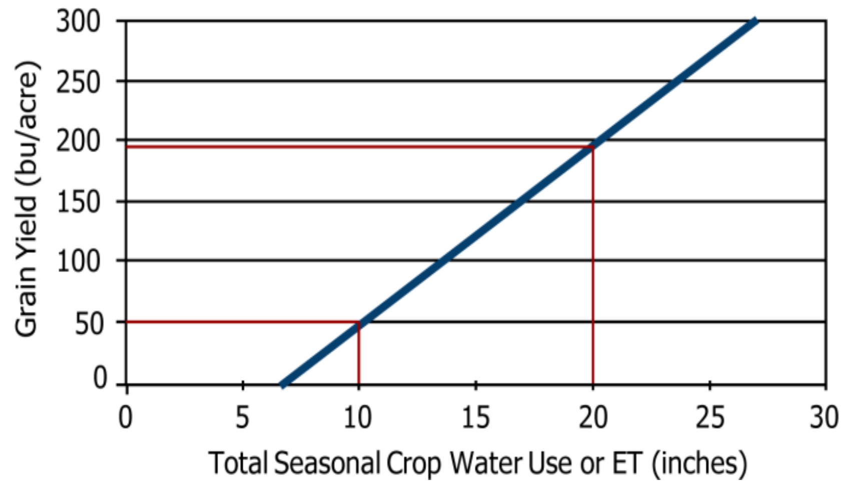

Figure 5.1. The positive, linear relationship between total seasonal crop water use or evapotranspiration (ET) and grain yield. Source: Shanahan and Groeteke (2011) based on Grassini et al., Agric. For. Meteor., v. 149, pp. 1254-1256.

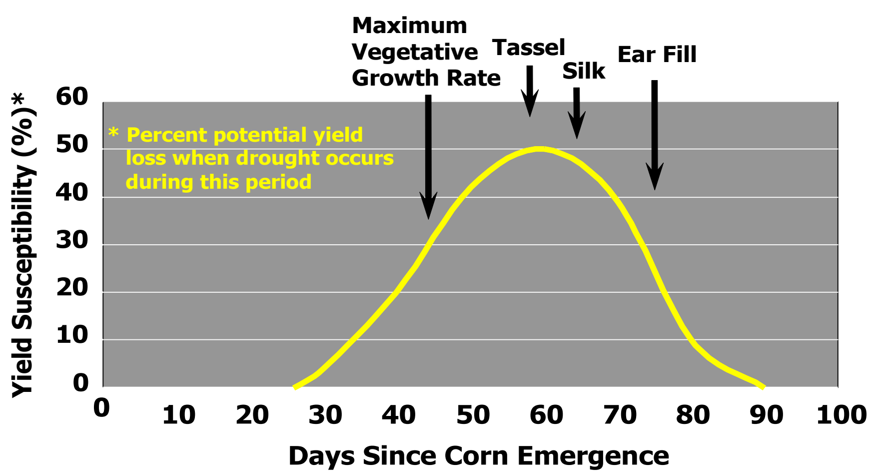

Figure 5.2. Yield susceptibility to water stress during corn development. Source: Shanahan and Groeteke (2011) based on Sudar et al., Trans. ASAE, v. 24, pp. 97-102.

CHAPTER 6

IN SEASON MONITORING

Remote Sensing Basics

Remote sensing technology uses light reflected from objects to provide images that contain information about the target of interest (Aggarwal 2004). Incident solar radiation or electromagnetic radiation (EMR) from the sun is reflected or emitted from the earth and sensed by remote sensors (Aggarwal 2004). The interaction between EMR and objects on earth's surface results in varying proportions of the incident EMR being reflected, absorbed, and transmitted. The fate of EMR on an object's surface is a function of the object's surface characteristics and varies by wavelengths. Remote sensing utilizes platforms like airplanes, satellites, and close-range (proximal) to collect data (Gunzenhauser and Shanahan 2013).

Remote sensing consists of five basic steps. Energy from EMR contacts the target of interest resulting in an interaction with the target. The resulting EMR depends on the characteristics of the target and the radiation (Aggarwal 2004). A remote sensor collects and records the EMR resulting from this target interaction. The sensor transmits data to a receiving and processing station to process the data into an image (Aggarwal 2004). The processed image is visually, digitally, and/or electronically interpreted to provide information about the target. The extracted information from the image is used to provide new knowledge about the target (Aggarwal 2004).

The remote sensing tool collects the unique EMR spectral behavior about the surface or target to infer information about its size, type, structure, or condition

(Aggarwal 2004). Remote sensing tools can be active or passive. A passive system utilizes natural light emitted from the sun as the source of energy that is measured. An active system uses its own source of light to measure reflected light (Gunzenhauser and Shanahan 2013).

The pixel size that creates the image is defined by resolution. Resolution is the system's ability to sense differences between similar signals (Shaw and Burke 2003), and there are four types of resolutions associated with remote sensing image data. Radiometric resolution is the sensor's sensitivity to detect differences in the signal strength as data is recorded. Spatial resolution is the level of distinction that can be made between the smallest angular separation (distance) between objects (Shaw and Burke 2003). It is the smallest target that can be detected on an image. A higher spatial resolution occurs when a smaller ground area is represented by a pixel (Shaw and Burke 2003).

Temporal resolution is the time period between imagery recordings. Spectral resolution is the number of spectral bands or wavelength intervals used when measuring the objects of interest. Hyperspectral imaging has high spectral resolution and collects images simultaneously with hundreds of narrow spectral bands (Shaw and Burke 2003). Multi-spectral imaging utilizes wider and fewer bands to collect images. Correct selection of spectral bands results in being able to increase the contrast between the target and its background (Shaw and Burke 2003).

Plant Physiological Features Used for Remote Sensing Detection

The unique chemical and physical properties of an object (e.g. crop canopy) reflect and absorb different EMR. The photosynthetically active radiation (PAR) occurs at a wavelength range from 400-700 nm. Chlorophyll, carotenoids, and anthocyanins all absorb radiation in the PAR region (Taiz and Zeiger 2010). The greater the chlorophyll content, the more absorption of PAR occurs in a leaf (Taiz and Zeiger 2010).

PAR has a high energy per photon, and blue (430-475 nm) and red (640-700 nm) photons excite chlorophyll pigments to help drive photosynthesis. A leaf with less chlorophyll does not need to absorb as much PAR because it has a lower rate of photosynthesis (Taiz and Zeiger 2010). The far-red (~700 nm) and red (~640 nm) photons region excites chlorophyll pigments in photosystem I and II, respectively. The energy and electrons are transferred from chlorophyll pigments to reaction centers, and then passed to the electron transport chain. The photosystem II and I and the electron transport chain are used to generate ATP and NADPH needed for the dark reaction of photosynthesis (Taiz and Zeiger 2010).

Radiation above 700 nm is reflected or transmitted. Near Infra-Red (NIR) light (wavelengths between 760-900 nm) is mostly reflected by the leaf as it does not contribute to photosynthesis (Taiz and Zeiger 2010). The green region (wavelengths between 520-600 nm) is reflected more by the leaf as its energy does not play as significant of a role in photosynthesis like the blue (450-520 nm) and red (630-680 nm) region (Gunzenhauser and Shanahan 2013). Figures 6.1 and 6.2 illustrate how a corn leaf absorbs more visible light in the blue and red regions, less in the green region, and significantly less in the NIR region. Many commercial systems use spectral reflectance of visible and NIR light properties of leaves for remote sensing imagery (Gunzenhauser and Shanahan 2013).

Leaf temperature as determined by reflectance in the thermal infrared provides a measurement of the plant's water status. Transpiration as a method for cooling is reduced as the plant decreases the amount of available water in the soil. When plant available soil water is depleted, plant temperatures increase compared to a well-watered reference crop or the ambient air temperature. The range of plant temperature fluctuates based on the soil water availability, the atmospheric evaporative demand, and transpirational characteristics of the crop (Pinter et al. 2003).

Spectral Transformations to Improve Crop Management

Issues in a field can be identified from imagery providing information such as plant stress, nitrogen deficiency, and plugged irrigation nozzles. Many of the commercial remote sensing systems use the visible and NIR light regions to detect abnormalities and changes in the crop canopy (Gunzenhauser and Shanahan 2013). As more chlorophyll is made in the plant, the plant canopy will absorb more visible light and reflect more NIR light. Light characteristics of a canopy, such as NIR reflectance values, are typically used in spectral transformations (e.g. vegetation indices) to remove background data (e.g. reflectance from soil) that does not originate from the target of interest (Gunzenhauser and Shanahan 2013).

The most widely used vegetative index is Normalized Difference Vegetation Index (NDVI), and red and NIR bands are used to calculate NDVI (Gunzenhauser and Shanahan 2013). The NDVI equation uses vegetation reflectance values in the formula:

(NIR-RED)/(NIR+RED). The value of NDVI ranges from -1 to 1, and it increases as green tissue or crop canopy increases. Other vegetation indices are also used as NDVI doesn't measure vegetation characteristics accurately when there is a significant amount of green tissue (Gunzenhauser and Shanahan 2013). The reflectance of the red wavelength becomes less sensitive to changes in chlorophyll a concentrations increase above 5 μg/cm^2 (Gitelson et al. 1996).

The Normalized Difference Vegetation Index-Green, or NDVIG (see Figure 6.3) is better able to identify characteristics in the crop canopy when there is more green tissue past the V9 crop growth stage for corn. The green wavelength reflectance is sensitive to chlorophyll a concentrations from 0.3 to 45 μg/cm^2 (Gitelson et al. 1996). The green and NIR bands are used to calculate NDVIG. The NDVIG equation is calculated using reflectance values: (NIR-GREEN)/(NIR+GREEN). Typically, NDVIG is correlated to water stress, where low NDVIG values later in the growing season with more crop canopy indicate that the plants are experiencing water stress (Gunzenhauser and Shanahan 2013).

Plant water status can also be inferred from plant temperature when measured by thermal infrared indices. Thermal reflectance in the infrared region is sensitive to water stress in plants because reflectance in the thermal infrared region increases as plants become water stressed (Pinter et al. 2003). Some thermal infrared indices include Crop Water Stress Index (CWSI) and Water Deficit Index (WDI) (Pinter et al. 2003).

Crop Water Stress Index is one way to use reflectance data of the thermal infrared region for management decisions. CWSI is defined as $(dT-dT_1)/(dT_u – dT_1)$ where dT is the temperature difference between crop canopy and air, dT_u is the upper limit of a nontranspiring crop, and dT_1 is lower limit of well-watered crop (Idso 1982). The upper and lower limits can be measured by changes in the vapor pressure deficit. The CWSI values range from zero to one with one indicating the plant is severely water stressed (Idso 1982). The WDI calculations estimate the plant water status using a vegetative index and temperatures of the soil surface and air. WDI minimizes soil noise that affects CWSI values before full canopy cover since dry soil has higher temperature than the air (Moren et al. 1994).

The use of imagery from remote sensing to monitor fields during the growing season does not mean that scouting of fields is not needed (Gunzenhauser and Shanahan 2013). Areas in the field with issues such as abnormalities detected from remotely sensed images should be scouted before making management decisions. Remote sensing can be used as a tool to detect and direct scouting efforts in a field (Gunzenhauser and Shanahan 2013).

Field monitoring from scouting and remote sensing images provides information for decision making about irrigation scheduling and making adjustments to the VRI prescription (Gunzenhauser and Shanahan 2013). Remote sensing images provide guidance on the efficient water application to better meet the crop water status (Stafford 2000). Remote sensing imagery can improve precision of management zones for VRI since it gives another estimate of field variation and crop yield (Doerge 1998).

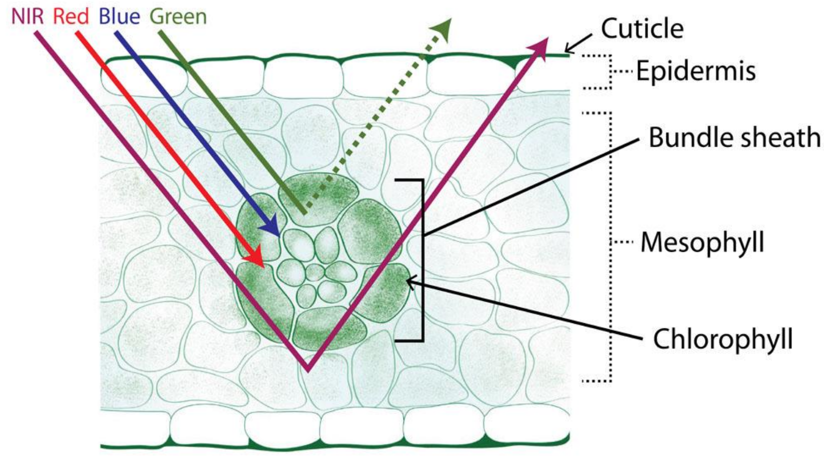

Figure 6.1. The cross-section of a corn leaf showing the interaction of EMR with the anatomical components of the leaf. Figure is courtesy of DuPont Pioneer.

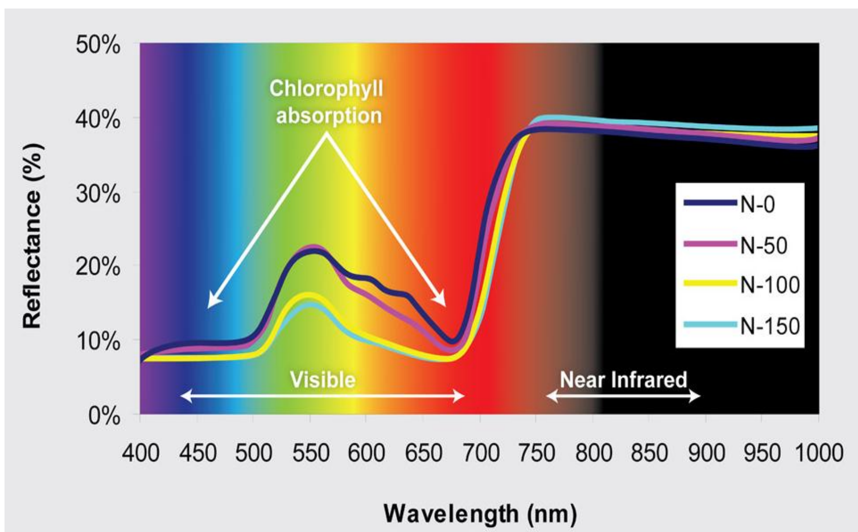

Figure 6.2. The differences in the reflectance spectrum for corn plants receiving four rates of N fertilizer. Figure is courtesy of DuPont Pioneer.

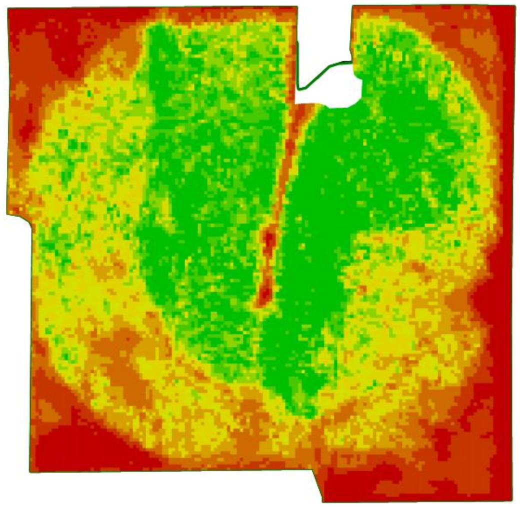

Figure 6.3. NDVIG image during the corn growing season and showing plant stress in the southwest part of the field with sandy soil. Figure is courtesy of DuPont Pioneer.

REFERENCES

Aggarwal, S. 2004. Principles of remote sensing, pp. 23-38. In M. V. K. Sivakumar, P. S. Roy, K. Harmsen and S. K. Saha (eds.), Satellite Remote Sensing and GIS Applications in Agricultural Meteorology, July 7-11, 2003, Dehra Dun, India. World Meteorological Organisation, Geneva, Switzerland.

AgSense. 2012. AgSense. http://www.agsense.net/home.

Ali, M. H. 2011. Water application methods, pp. 35-63. In M. H. Ali (ed.), Practices of Irrigation & On-Farm Water Management, vol. 2. Springer, New York, NY.

Brase, T. A. 2006. Precision Agriculture, 1st ed. Thomson/Delmar Learning, Clifton Park, NY.

Cox, S. 2002. Information technology: the global key to precision agriculture and sustainability. Comput. Electron. Agric. 36:93-111.

CropMetrics. 2013. Virtual agronomist. http://cropmetrics.com/services/virtual-agronomist/.

Davis, G., W. Casady, and R. Massey. 1998. Precision agriculture: an introduction, https://mospace.library.umsystem.edu/xmlui/bitstream/handle/10355/9432/PrecisionAgricultureIntroduction.pdf?sequence=3. University of Missouri Office of Extension.

Doerge, T. 1998. Defining management zones for precision farming. Pioneer Hi-Bred.

Evans, R. G., and B. A. King. 2012. Site-specific sprinkler irrigation in a water-limited future. Trans. ASABE 55:493-504.

Evans, R. G., J. LaRue, K. C. Stone, and B. A. King. 2013. Adoption of site-specific variable rate sprinkler irrigation systems. Irrig. Sci. 31:871-887.

Evans, R. G., and E. J. Sadler. 2013. Site-specific irrigation water management, pp. 172-190. In M. A. Oliver, T. Bishop and B. Marchant (eds.), Precision Agriculture for Food Security and Environmental Protection. Earthscan Publishers/Taylor & Francis, London, UK.

Fairchild, D. S. 1988. Soil information system for farming by kind of soil, pp. 159-164. In Proceedings, International Interactive Workshop on Soil Resources: Their Inventory, Analysis and Interpretations for Use in 1990's. University of Minnesota, St. Paul, MN.

Gitelson, A. A., Y. J. Kaufman, and M. N. Merzlyak. 1996. Use of a green channel in remote sensing of global vegetation from EOS-MODIS. Rem. Sens. Environ. 58:289-298.

Grassini, P., H. Yang, and K. G. Cassman. 2009. Limits to maize productivity in Western Corn-Belt: a simulation analysis for fully-irrigated and rainfed conditions. Agric. For. Meteor. 149:1254-1256.

Grisso, R., M. Alley, P. McClellan, D. Brann, and S. Donohue. 2009. Precision farming: A comprehensive approach, http://pubs.ext.vt.edu/442/442-500/442-500.html. Virginia Cooperative Extension.

Gunzenhauser, B., and J. Shanahan. 2013. Use of remote sensing imagery for improving crop management decisions, https://www.pioneer.com/home/site/us/agronomy/library/remote-sensing-imagery/. Pioneer Hi-Bred.

Gunzenhauser, B., J. Shanahan, and E. Lund. 2012. Utilizing on-the-go soil sensing devices to improve definition of management zones, https://www.pioneer.com/home/site/us/agronomy/soil-sensing-mgmt-zones/. Pioneer Hi-Bred.

Idso, S. B. 1982. Non-water-stressed baselines: a key to measuring and interpreting plant water stress. Agric. Meteor. 27:59-70.

Johnson, B., C. Thompson, A. Giri, and S. Van NewKirk. 2011. Nebraska irrigation fact sheet, http://agecon.unl.edu/c/document_library/get_file?uuid=a9fcd902-4da9-4c3f-9e04-c8b56a9b22c7&groupId=2369805&.pdf. University of Nebraska.

Johnson, C. E., R. L. Schafer, and S. C. Young. 1983. Controlling agricultural machinery intelligently, pp. 114-119. In J. V. Stafford (ed.), Proceedings of National Conference on Agricultural Electronics Applications. American Society of Agricultural Engineers, St. Joesph, MI, USA.

Jones, H. G. 2004. Irrigation scheduling: advantages and pitfalls of plant-based methods. J. Exp. Bot. 55:2427-2436.

Kitchen, N. R., S. T. Drummond, E. D. Lund, K. A. Sudduth, and G. W. Buchleiter. 2003. Soil electrical conductivity and topography related to yield for three contrasting soil-crop systems. Agron. J. 95:483-495.

Kranz, W. L., R. G. Evans, F. R. Lamm, S. A. O’Shaughnessy, and R. T. Peters. 2012. A review of mechanical move sprinkler irrigation control and automation technologies. Appl. Eng. Agric. 28:389-397.

Krishna, K. R. 2013. Precision farming: soil fertility and productivity aspects. Apple Academic Press Inc., Waretown, NJ.

LaRue, J., and R. Evans. 2012. Considerations for variable rate irrigation. Proc. 24th Annu. Cent. Plains Irrig. Conf. 111-116.

Lu, Y. C., E. J. Sadler, and C. R. Camp. 2005. Economic feasibility study of variable irrigation of corn production in southeast coastal plain. J. Sustainable Agric. 26:69-81.

Matthews, J. 1983. Some challenges for engineers in agriculture. J. R. Agric. Soc. Engl. 144:146-158.

McLoud, P. R., R. Gronwald, and H. Kuykendall. 2007. Precision agriculture: NRCS support for emerging technologies, http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=18475.wba. U.S. Department of Agriculture Natural Resources Conservation Service.

Moran, M. S., T. R. Clarke, Y. Inoue, and A. Vidal. 1994. Estimating crop water deficit using the relation between surface-air temperature and spectral vegetation index. Remote Sens. Environ. 46:246-263.

Norwood, C. A. 2000. Water use and yield of limited-irrigated and dryland corn. Soil Sci. Soc. Am. J. 64:365-370.

Perry, C., and S. Pocknee. 2003. Precision pivot irrigation controls to optimize water application, pp. 86-92. In Understanding & Addressing Conservation and Recycled Water Irrigation. The Proceedings of the 2003 Irrigation Association Meeting, San Diego, CA.

Phene, C. J., R. J. Reginato, B. Itier, and B. R. Tanner. 1990. Sensing irrigation needs, pp. 207-264. In G. J. Hoffman, T. A. Howell and K. H. Solomon (eds.), Management of Farm Irrigation Systems. American Society of Agricultural Engineers, St. Joseph, MI.

Pinter, P. J., J. L. Hatfield, J. S. Schepers, E. M. Barnes, M. S. Moran, C. S. T. Daughtry, and D. R. Upchurch. 2003. Remote sensing for crop management. Photogramm. Eng. and Remote Sens. 69:647-664.

Plante, A. F. 2006. Soil biogeochemical cycling of inorganic nutrients and metals, pp. 391-434. In E. A. Paul (ed.), Soil Microbiology, Ecology, and Biochemistry, 3rd ed. Academic Press, Oxford, UK.

Rains, G. C., and D. L. Thomas. 2000. Precision farming: An introduction, http://athenaeum.libs.uga.edu/bitstream/handle/10724/12223/B1186.pdf?sequence=1 University of Georgia Cooperative Extension Service.

Robertson, G. P., and P. M. Groffman. 2006. Nitrogen transformations, pp. 341-365. In E. A. Paul (ed.), Soil Microbiology, Ecology, and Biochemistry, 3rd ed. Academic Press, Oxford, UK.

Sadler, E., R. Evans, K. Stone, and C. Camp. 2005. Opportunities for conservation with precision irrigation. J. Soil Water Conserv. 60:371-378.

Schepers, A. R., J. F. Shanahan, M. A. Liebig, J. S. Schepers, S. H. Johnson, and A. Luchiari. 2004. Appropriateness of management zones for characterizing spatial variability of soil properties and irrigated corn yields across years. Agron. J. 96:195-203.

Schimmelpfennig, D., and R. Ebel. 2011. On the doorstep of the information age: Recent adoption of precision agriculture, http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib80.aspx#.UuksEPldWSo. United States Department of Agriculture, Economic Research Service.

Schneekloth, J. P., T. Bauder, and N. Hansen. 2009. Limited irrigation management: principles and practices, http://www.ext.colostate.edu/pubs/crops/04720.html. Colorado State University Cooperative Extension.

Shanahan, J., and J. Groeteke. 2011. Irrigation and agronomic management of corn grown under limited water supplies, https://www.pioneer.com/home/site/us/agronomy/library/template.CONTENT/guid.5BD9D4C1-AC5D-FF32-4EBA-E8B295C89093. Pioneer Hi-Bred.

Shanahan, J., and B. Gunzenhauser. 2011. Using multi-year yield analysis to create management zones for variable-rate seeding, https://www.pioneer.com/home/site/us/template.CONTENT/products/field-technology-tips/guid.F71F86E6-406F-9711-7FE0-2DA3D30957CA. Pioneer Hi-Bred.

Shaw, G. A., and H. K. Burke. 2003. Spectral imaging for remote sensing. Lincoln Lab. J. 14:3-28.

Stafford, J. V. 2000. Implementing precision agriculture in the 21st century. J. Agric. Eng. Res. 76:267-275.

Stafford, J. V. 2006. The role of technology in the emergence and current status of precision agriculture, pp. 19-56. In A. Srinivasan (ed.), Handbook of Precision Agriculture: Principles and applications. The Haworth Press, Inc, New York, NY.

Sudar, R. A., K. E. Saxton, and R. G. Spomer. 1981. A predictive model of water stress in corn and soybeans. Trans. ASAE 24:97-102.

Taiz, L., and E. Zeiger. 2010. Plant physiology, 5th ed. Sinauer Associates, Inc., Sunderland, MA.

University of Nebraska-Lincoln. 2012. Center pivot irrigation management handbook. University of Nebraska-Lincoln Extension, Lincoln, NE.

US Department of Defense. 2007. DoD Permanently Discontinues Procurement Of Global Positioning System Selective Availability. http://www.defense.gov/releases/release.aspx?releaseid=11335.

USDA National Agricultural Statistics Service. 2007. Census of agriculture. http://www.agcensus.usda.gov/Publications/2007/Full_Report/usv1.pdf.

Valmount Industries. 2013. Valley irrigation: A leader in precision irrigation. http://www.valleyirrigation.com/valley-irrigation/us/home.

Veris Technology. 2013. Soil EC. http://www.veristech.com/products/soilec.aspx.

Werner, H. 2002. Measuring soil moisture for irrigation water management, http://pubstorage.sdstate.edu/AgBio_Publications/articles/FS876.pdf. SDSU Cooperative Extension Service.

Zhang, N., M. Wang, and N. Wang. 2002. Precision agriculture—a worldwide overview. Comput. Electron. Agric. 36:113-132.